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TOP-DOWN ANALYSIS OF SHIP HULL COMPONENTS

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TOP-DOWN ANALYSIS OF SHIP HULL COMPONENTS

by
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CONTRACTOR REPORT

Prepared for

Defence Research Establishment Atlantic

Centre de Recherches pour la Défense Atlantique

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Abstract

A comparative structural analysis of a ship hull by top-down modelling is described. A finite element analysis of a loaded large coarse model of a ship hull was carried out. After the analysis a section of the model was extracted and displacements from the large model were applied to its boundary nodes as prescribed displacements. The extracted model was loaded with its portion of the load. The displacements and stresses obtained from a finite element analysis of the extracted model were compared with those at corresponding nodes of the coarse model. A reduced size portion of the hull was extracted from the same region and the displacements and stresses compared with those of the coarse and extracted model. The reduced extracted model grid and loading were then refined and displacements and stresses obtained and compared with those of the unrefined model. Then a portion of the refined model was extracted which contained a single frame and portions of the surrounding beams and plates. The displacements and stresses of this model again were compared with those of the model from which it was extracted. The stresses in the frame cross-section along its length are shown graphically.

Résumé

Le présent document décrit l'analyse structurale, par modélisation descendante, d'une coque de navire. On a d'abord appliqué la méthode d'analyse des éléments finis à un modèle grossier de coque de grande taille chargée. À l'issue de cette analyse, on a isolé une section (transversale) de ce modèle de grande taille et les valeurs de déplacement du modèle complet ont été appliquées aux noeuds d'état limite de la section et considérées ensuite comme les déplacements prescrits. La section de modèle isolé a alors reçu sa portion de la charge. Les déplacements et les contraintes obtenus par les méthodes d'analyse des éléments finis du modèle isolé ont ensuite été comparés à ceux des noeuds correspondants du modèle grossier. Une portion à échelle réduite de la coque a aussi été extraite de cette même zone et ses déplacements et containtes ont été comparés avec ceux du modèle grossier et ceux du modèle isolé. On a ensuite raffiné la grille et les données de charge du modèle réduit isolé, puis les valeurs de contrainte obtenues ont été comparées à celles du modèle non raffiné. On a ensuite extrait une portion du modèle raffiné, portion ne comportant qu'une seule membrure, ainsi que des parties des serres ou des plaques de bordé avoisinantes. On a finalement comparé les déplacements et les containtes de ce modèle avec ceux du modèle entier dont il avait été tiré. Les contraintes le long de la membrure (coupe transversale) sont représentées graphiquement.

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1 Introduction

To predict stresses in ship hull components such as plates and frames, due to balance-on-a-wave loading, a common approach is to model the ship as an equivalent beam. The bending moment is estimated and the hull bending stresses are obtained. These are combined with the plate and local beam bending stresses due to hydrostatic pressure to predict the local combined state of stress. Another approach is to generate a finite element model of a small portion of the hull sometimes in the form of a grillage of beams with plating attached. With an estimate of the loading and the boundary conditions the model is subjected to a finite element analysis to obtain displacements and stresses.

A third approach is a process known as top-down modelling which is based on predicting stresses by starting with a coarse finite element model of a large portion of the ship hull using beam and plate elements as shown in Figure 1. The model can be loaded with a classic loading case such as balance-on-a-wave which is applied as nodal point pressures. The model is then subjected to a finite element analysis mainly to obtain global displacements and stresses in a region of interest. The region is extracted as a much smaller model but with the same degree of mesh coarseness. The nodal displacements at the extracted model boundaries from the large model are applied as boundary conditions together with any loading that may be present. This system, including the loading, is refined with a refining program such as VASFEM[1] to the degree that the detail requires. A still smaller region can be examined by extracting from the previous extracted model until the detail is too complex to be represented by simple plates and general beams. At this stage the beams and connections must be built up from plate elements either by hand or by the use of a modelling program such as VASGEN[2] or PATRAN[3]. Enough of the surrounding structure must be included so the displacements obtained from each preceding analysis will ensure that the strain energy is properly distributed through the refined mesh.

This report describes a study carried out for the Defence Research Establishment Atlantic on the top-down modelling of ship hull components to predict displacements and stresses.

2 Coarse Model

The coarse model of a ficticious hull, used in the study, was generated using the program SHPHUL[4]. As shown in Figure 1 it was composed of an assembly of general beam elements and four noded quadrilateral plate elements. Each plate element was bounded by two frames and two longitudinal beams in the form of general beam elements. The coarse model was then loaded with a hogging wave profile obtained from the balance on a wave program POSBOW[5] and applied by SHPHUL as shown in Figure 2. The load file including self weight was created by SHPHUL with the hydrostatic pressure applied as nodal point pressures as illustrated in Figure 3. To avoid the problem of accounting for distributed lumped masses to balance the resulting hydrostatic forces, the hull was supported at the extreme fore and aft corners as shown in Figure 4. A finite element analysis was carried out using the program VAST[6]. The resulting displacements and stresses are shown in Figure 5 and Figure 6 as color fringes obtained by using the VAST VIZUALIZER[7] post processing program.

3 Extracted Model

The next step carried out was the start of the top-down analysis. A section in the region of the high stress was extracted using the program EXTRACT[8]. The region of interest was identified on a display of the coarse model with the terminal cursor as shown in Figure 7. The extracted section displayed in Figure 8 had the boundary nodes identified with the screen cursor. The displacements from the coarse model associated with these nodes were automatically equivalenced and collected in a file as prescribed displacements to be read by VAST. During the extraction session the extracted model was loaded by the portion of the wave in which it was immersed as can be seen in Figure 9. At this stage all the necessary data had been created for a VAST analysis of the section. The resulting displacements and stresses are shown as color fringes on the model in Figure 10 and Figure 11.

4 Comparison of Coarse and Extracted Model Results

Because this is the first step in the top-down method it is important that there be good agreement between the two models with regard to displacements and stresses. Identical nodes in the two models were compared and are listed in Table 1. Because the stresses are calculated from the displacements, to obtain identical stresses at the corresponding nodes the displacements must agree to 6 or more decimal places. This is a very demanding requirement and may present problems in the case of complex stress situations. It is important to note that nodes 273 and 25, which are boundary nodes of the extracted model, have values that are identical with their corresponding nodes in the coarse model. These displacements were obtained from the coarse model and were applied to the boundary nodes as prescribed displacements. The stresses obtained at the boundary nodes show the poorest agreement with their corresponding nodes, in this case 1569 and 1337 of the coarse model. This is perhaps due to the nodal stresses being smoothed from two elements rather than from four which is the case at the internal nodes. If reasonable agreement cannot be achieved at this stage then there is no point of continuing to the next step which is to refine the grid of the extracted model. In any case, it is important to allow for the poor agreement of the boundary stresses with those of the coarser model by extracting a section large enough to put the boundary stresses outside the region of interest.

Table 1: Comparison of Coarse and Extracted Models Displacements and Stresses

Coarse Model			Extracted Model		
Node	Displacement (in.)	Stress (psi)	Node	Dispacements (in.)	Stress (psi)
1569	1.460375	8869.81	273	1.460375	9589.50
1568	1.579949	9973.13	272	1.579218	10013.36
1567	1.642356	10804.58	271	1.678901	10776.73
1566	1.763231	11584.58	270	1.760741	11534.01
1565	1.826440	12225.67	269	1.823647	12171.11
1564	1.869559	12674.29	268	1.866823	12625.28
1563	1.892779	12944.14	267	1.890414	12905.30
1562	1.896733	13031.65	266	1.895043	13011.21
1561	1.881818	12764.11	265	1.881126	12801.51
1337	1.851860	12386.62	25	1.851860	12664.31

5 Reduced Size Extracted Model

The effect of extracting a smaller portion from the coarse model was investigated by extracting a lower portion of the hull in the same region as the original extracted section. The geometry of this model is shown in Figure 12. The displacements in the form of color fringes are shown in Figure 13 and the stresses are shown in Figure 14. Table 2 is a comparison of the reduced model stresses and displacements with those of the coarse model. A graph of the stresses versus their distance from the forward perpendicular is shown for the three models in Figure 15.

Though it is more economical to extract a smaller region, it can be seen from the comparison of the stress results that there is a greater loss of accuracy between the reduced size extracted model and the coarse model than between the extracted model and the coarse model.

6 Refined Model

It was decided for the investigation to refine the reduced size extracted model using the refine option in VASFEM. It was refined to produce sixteen four noded plate elements between the frames and the longitudinal beams in a four by four grid. The model is shown in Figure 16. The hydrostatic pressure load was also refined at the same time. Unfortunately, as shown in Figure 17, the pressures generated were inaccurate as they started higher up on the model than the balance on a wave waterline. They also followed the immersed waterline in steps rather than a smooth curve introducing additional inaccuracies. It was decided to use the program EXTRACT to load the model which produced the results shown in Figure 18. The boundary conditions as shown in Figure 19, applied at the model edges, were limited to those displacements obtained from the coarse model, as VASFEM could not generate the multipoint

Table 2: Comparision of Coarse and Reduced Models Displacements and Stresses

Coarse Model			Reduced Model		
Node	Displacement (in.)	Stress (psi)	Node	Dispacements (in.)	Stress (psi)
1569	1.460375	8869.81	120	1.460375	9984.58
1568	1.579949	9973.13	119	1.576101	10202.63
1567	1.642356	10804.58	118	1.671063	10671.09
1566	1.763231	11584.58	117	1.749647	11315.20
1565	1.826440	12225.67	116	1.811075	11924.69
1564	1.869559	12674.29	115	1.854511	12401.37
1563	1.892779	12944.14	114	1.879889	12733.56
1562	1.896733	13031.65	113	1.887715	12934.38
1561	1.881818	12764.11	112	1.878216	12970.56
1337	1.851860	12386.62	11	1.851860	12995.98

constraints required for a three dimensional model. These were initially used with the unrefined reduced model and could be easily applied as the refining process retained their node numbers. Thus rather than attempt the laborious calculation required to determine the additional prescribed displacements it was decided to see if the principal of St. Venant would apply, as the final detail to be investigated was well removed from the model edges.

7 Comparision of the Refined Model with the Other Models Results

The reduced model and the refined reduced model displacements and stresses are compared along the keel line in Table 3 at the same node number locations which were not altered by the refining process. The displacements are also shown as color fringes in Figure 20. The keel line displacements and stresses were not the maximum stresses. They occur in the center of the plates which are now modelled by sixteen plate elements as shown in Figure 21. The maximum stresses were 31108 psi rather than the 12995 psi obtained when the plates were modelled with single plate elements. Again the stresses along the boundary were unreliable and were made even more so because the intermediate boundary nodes generated by the refining process were not assigned prescribed displacements. A plot comparing the different model stresses along the keel line is shown in Figure 22. The stresses along the keel line have increased about 4 percent over those of the other models.

Table 3: Comparision of Reduced and Refined Model Displacements and Stresses

Reduced Model			Refined Reduced Model		
Node	Displacement (in.)	Stress (psi)	Node	Dispacements (in.)	Stress (psi)
120	1.460375	9984.58	120	1.460375	21158.00
119	1.576101	10202.63	119	1.568218	10768.21
118	1.671063	10671.09	118	1.662297	11722.71
117	1.749647	11315.20	117	1.741629	12514.96
116	1.811075	11924.69	116	1.802987	13034.20
115	1.854511	12401.37	115	1.845855	13328.20
114	1.879889	12733.56	114	1.870019	13447.56
113	1.887715	12934.38	113	1.877715	13410.00
112	1.878216	12970.56	112	1.868800	12790.75
11	1.851860	12995.98	11	1.851860	26408.00

8 Extracted Model of a Single Frame and Portions of Longitudinal Beams

The program EXTRACT was used to extract from the refined reduced model part of a single frame in the bottom, including the keel, with portions of the connecting longitudinal beams and associated plates. This model was chosen several plates in from the edge to reduce the effect of the boundary conditions. It was loaded with it's portion of the pressure load and the boundary conditions were set as prescribed displacements extracted from the refined model. The model is shown in Figure 23 and the loading in Figure 24. The resulting displacements and stresses are shown in Figure 25 and Figure 26. The stresses shown are plate stresses and are close in value to those shown on the refined reduced model in Figure 20. The maximum stresses in the refined model were 31108 psi and 30156 psi in the small single frame model. With this model it was easier to determine the frame stresses because the general beam element has no graphics option available to display the stresses, and the beam results had to be obtained from the line printer output. The beam grid is shown in Figure 27 along with the beam cross-section. The points numbered 1 to 4 on the cross-section are where the stresses were computed. The cross-section stresses along the length of the frame transversely from the keel are shown in Figure 28. The maximum beam stress, which was -21000 psi, did not occur in the frame but at the longitudinal beam acting as the keel and meeting the frame at node 5 in Figure 27.

To this point the model generation, loading and boundary conditions were accomplished by the use of the programs SHPHUL, VASGEN, POSBOW, VASFEM and EXTRACT. The next logical step would be to model the frame and longitudinal beams of the single frame model with plate elements and apply the same loading and boundary conditions used in the single frame model. This stage could not be carried out in the time available as it would have required a considerable amount of manual model generation.

9 Conclusion

Top-down structural analysis of a ship hull was demonstrated down to the point where further modelling was beyond the capability of the general beam element and beams modelled with plate elements were required. The fringe patterns obtained from each of the top-down steps were in reasonable agreement. The procedure showed that the plating surrounded by beams must be modelled with at least a four by four grid of four noded plate elements to obtain reasonable plate bending stresses. The boundary conditions defined by displacements obtained from the previous model produced unreliable stress results at the boundaries due to averaging over only two elements. The stresses in one element or more in from the edge were of an acceptable accuracy. In the case of refining, the intermediate nodes generated at the boundaries need not be given prescribed displacements provided they are far enough from the region of detail being investigated. The top-down method in addition to allowing structural detail to be investigated also permitted realistic pressure loads to be applied.

To confirm the accuracy of the results, the coarse model should be refined to the degree of providing a four by four grid for the plates between frames and the results compared with those obtained using the top-down procedure. The single frame model should be extended by modelling the frame and connecting beams with plate elements. The triangular plate element and the new four node plate element in the next version of VAST should be tested with the top-down procedure.

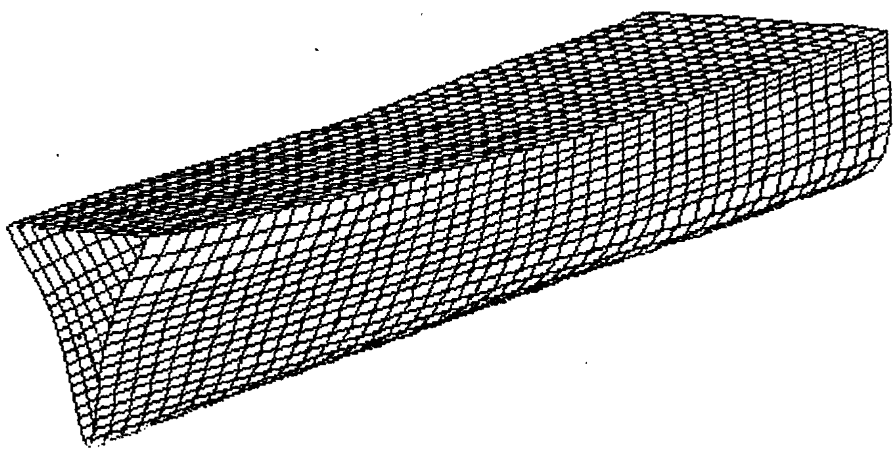

Figure 1: Coarse Finite Element Model of a Ship Hull

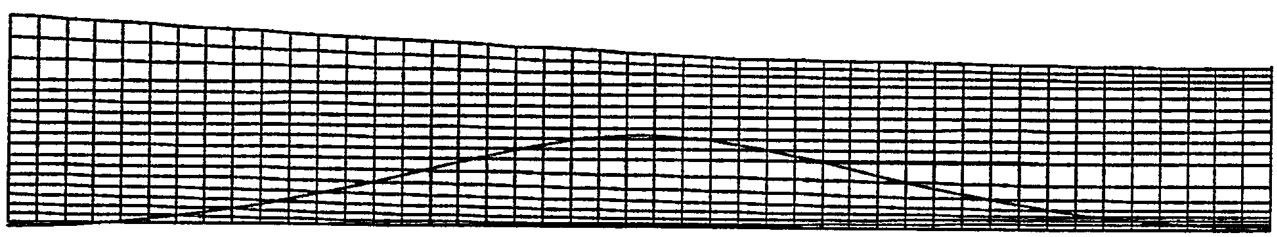

Figure 2: Balance on a Wave of the Coarse Hull Model

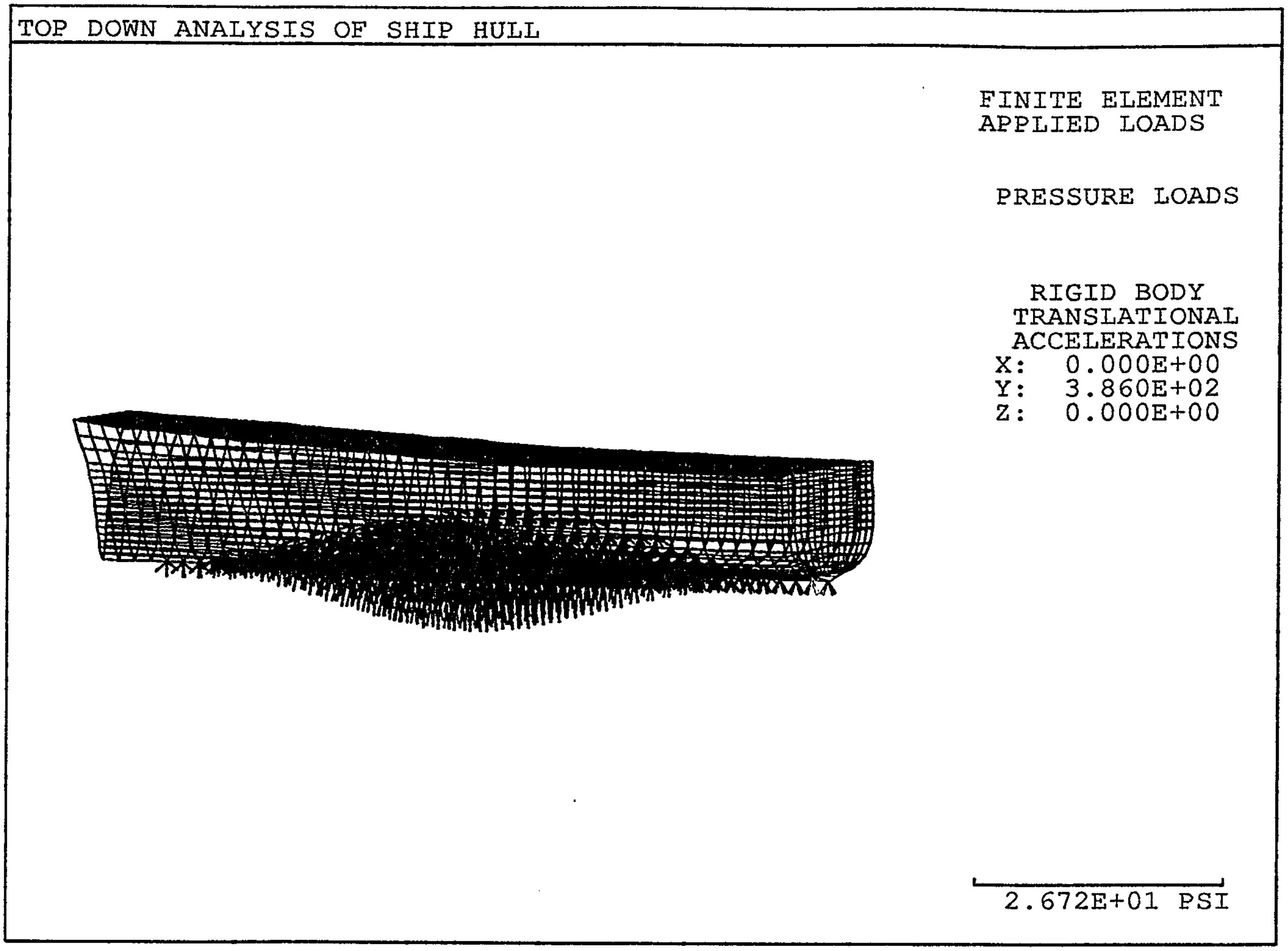

Figure 3: Balance on a Wave Pressure Loading on Coarse Hull Model

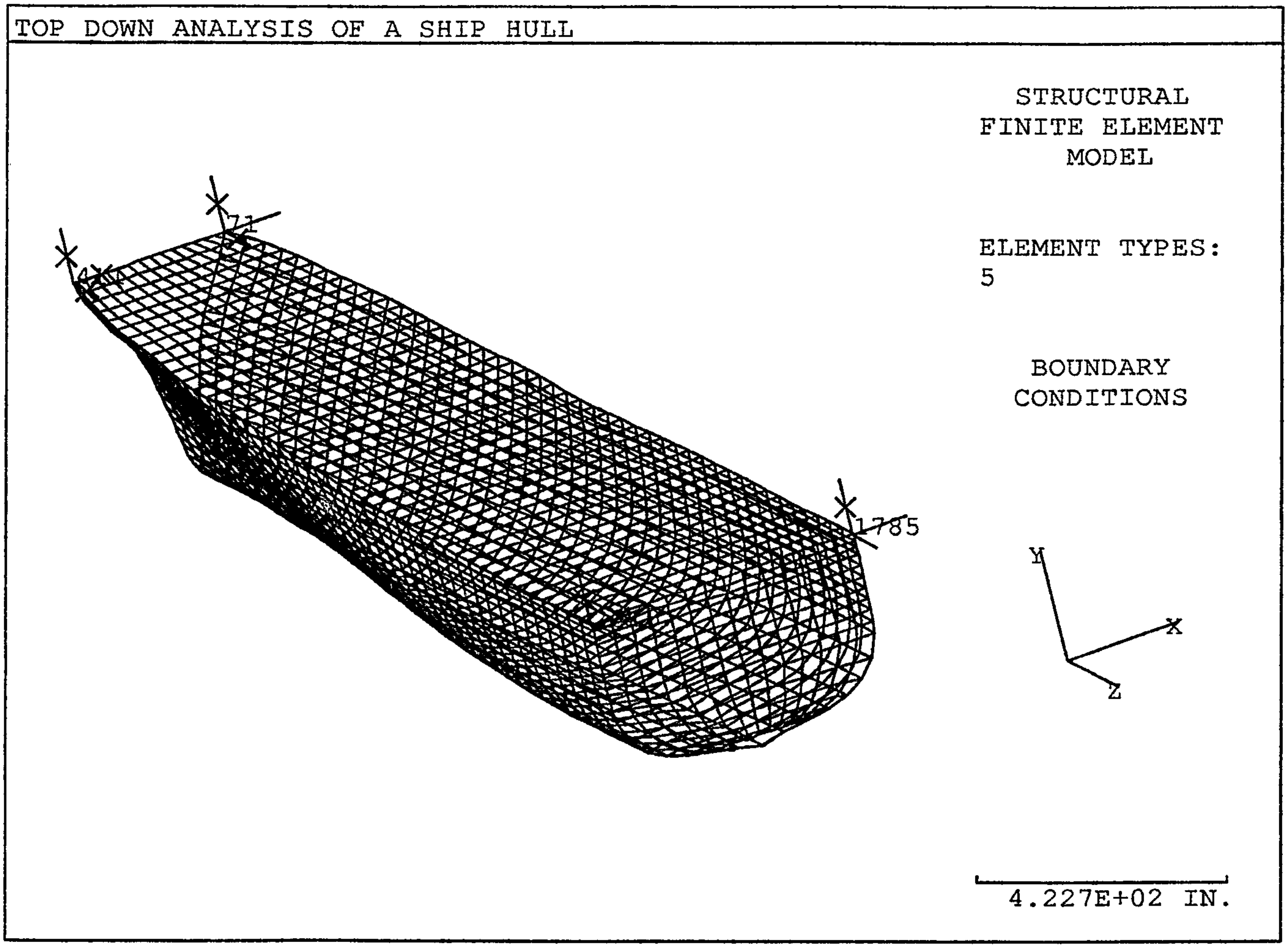

Figure 4: Support Points on the Hull to Obtain a Static Balance

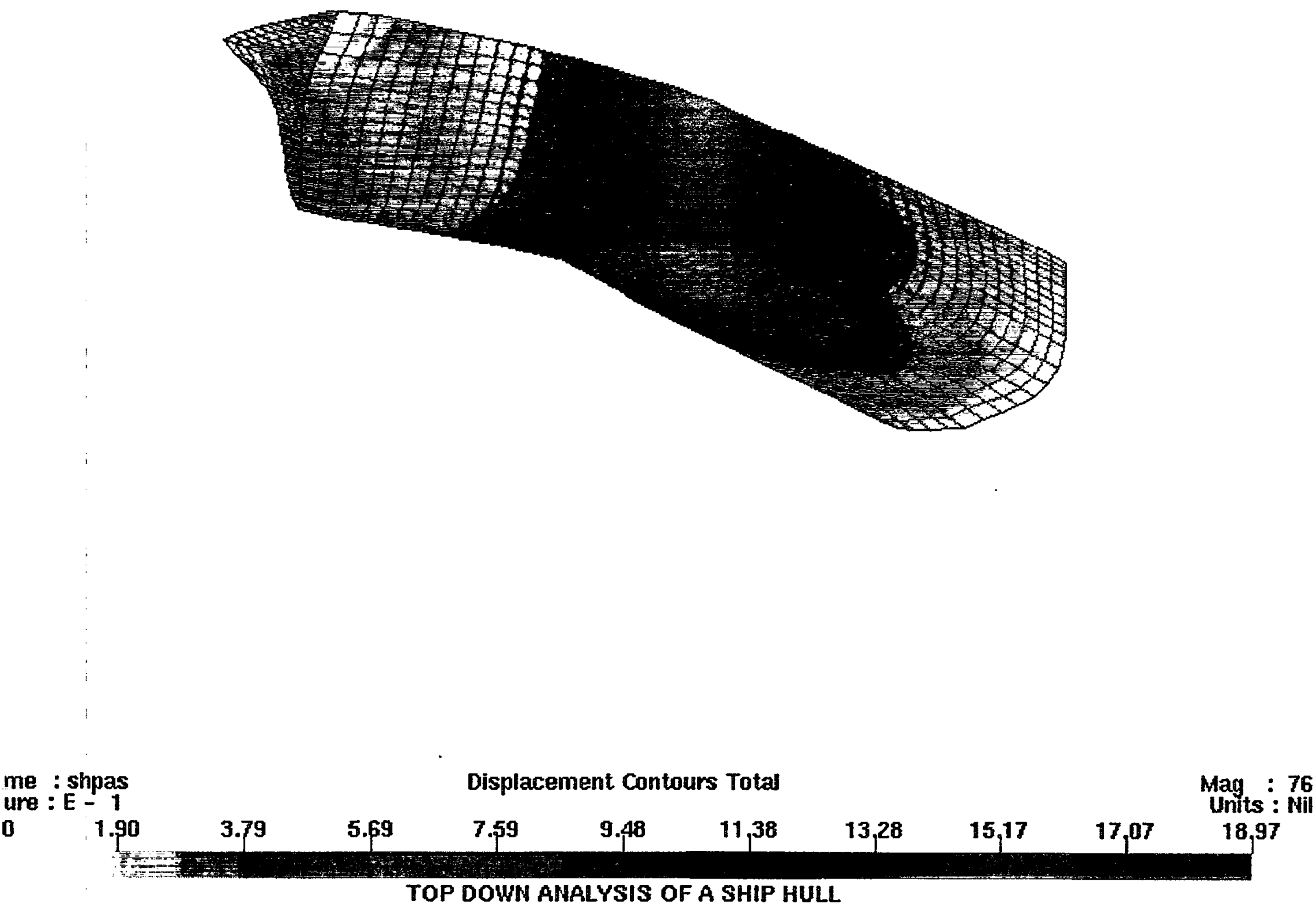

Figure 5: Static Displacements Fringes on Hull due to Wave Loading

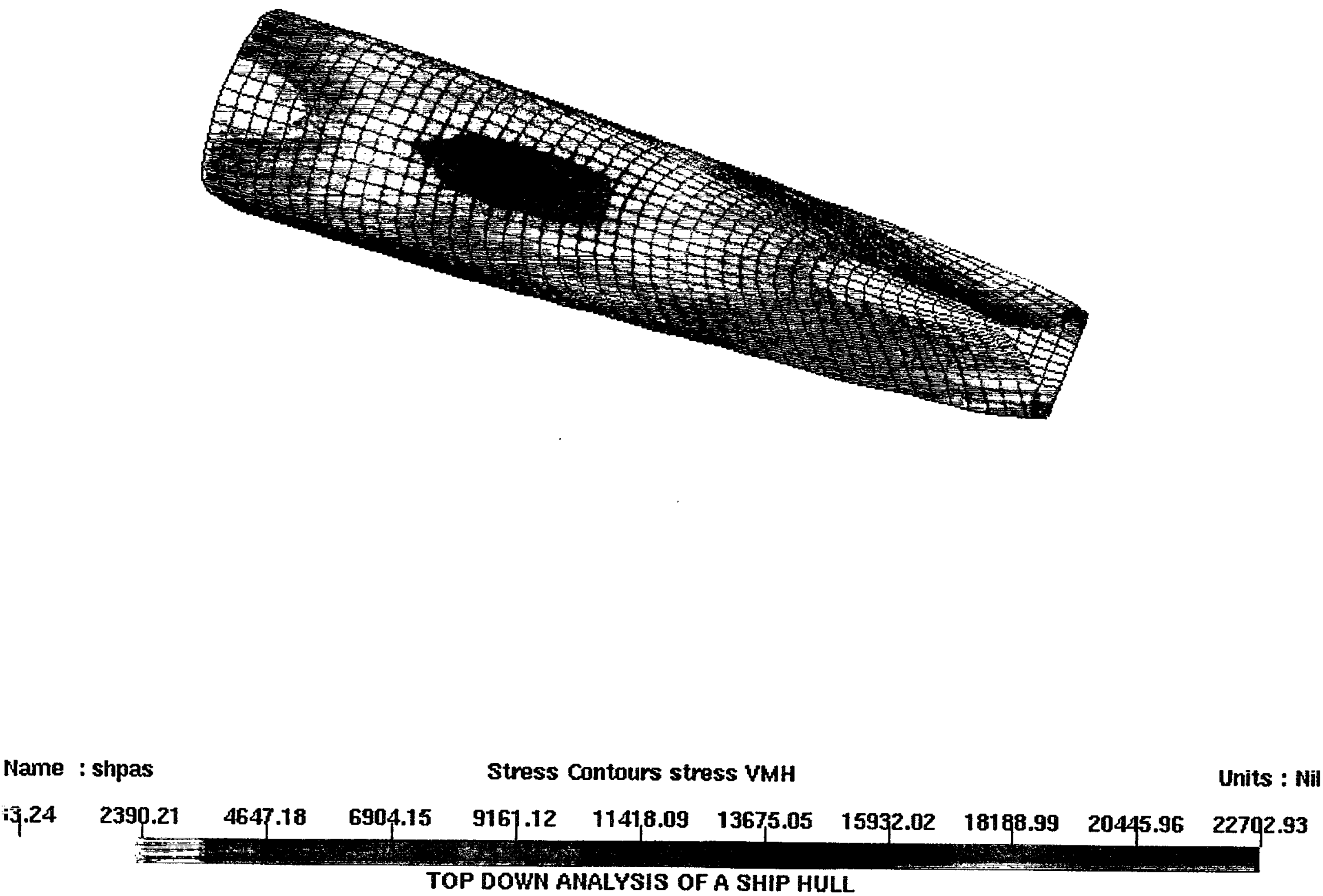

Figure 6: Static Von Mises Stress Fringes on Hull due to Wave Loading

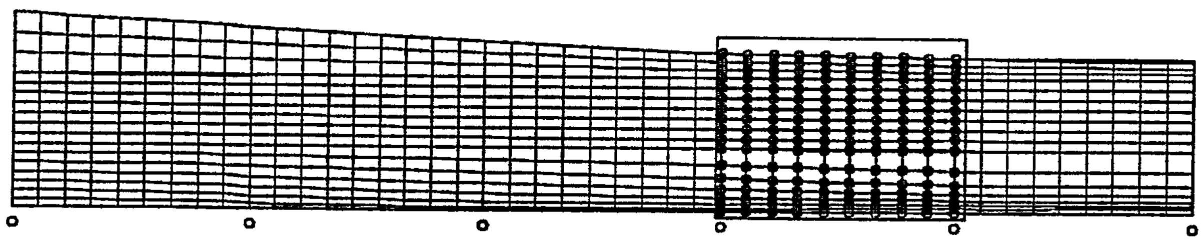

Figure 7: Identification with the Screen Cursor of the Section to be Extracted

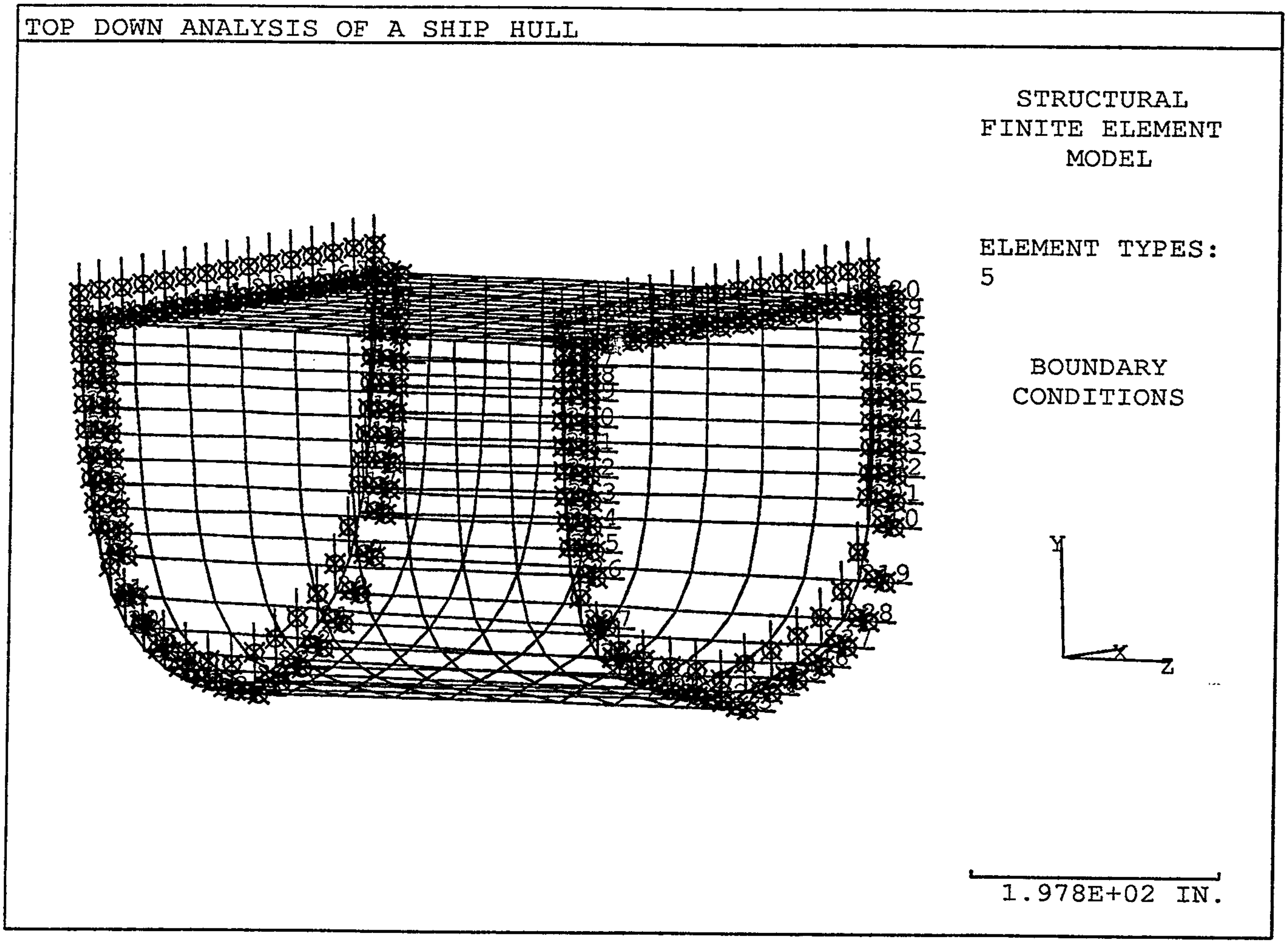

Figure 8: The Extracted Section with the Boundary Nodes Identified

Figure 9: Balance on a Wave Loading of the Extracted Section

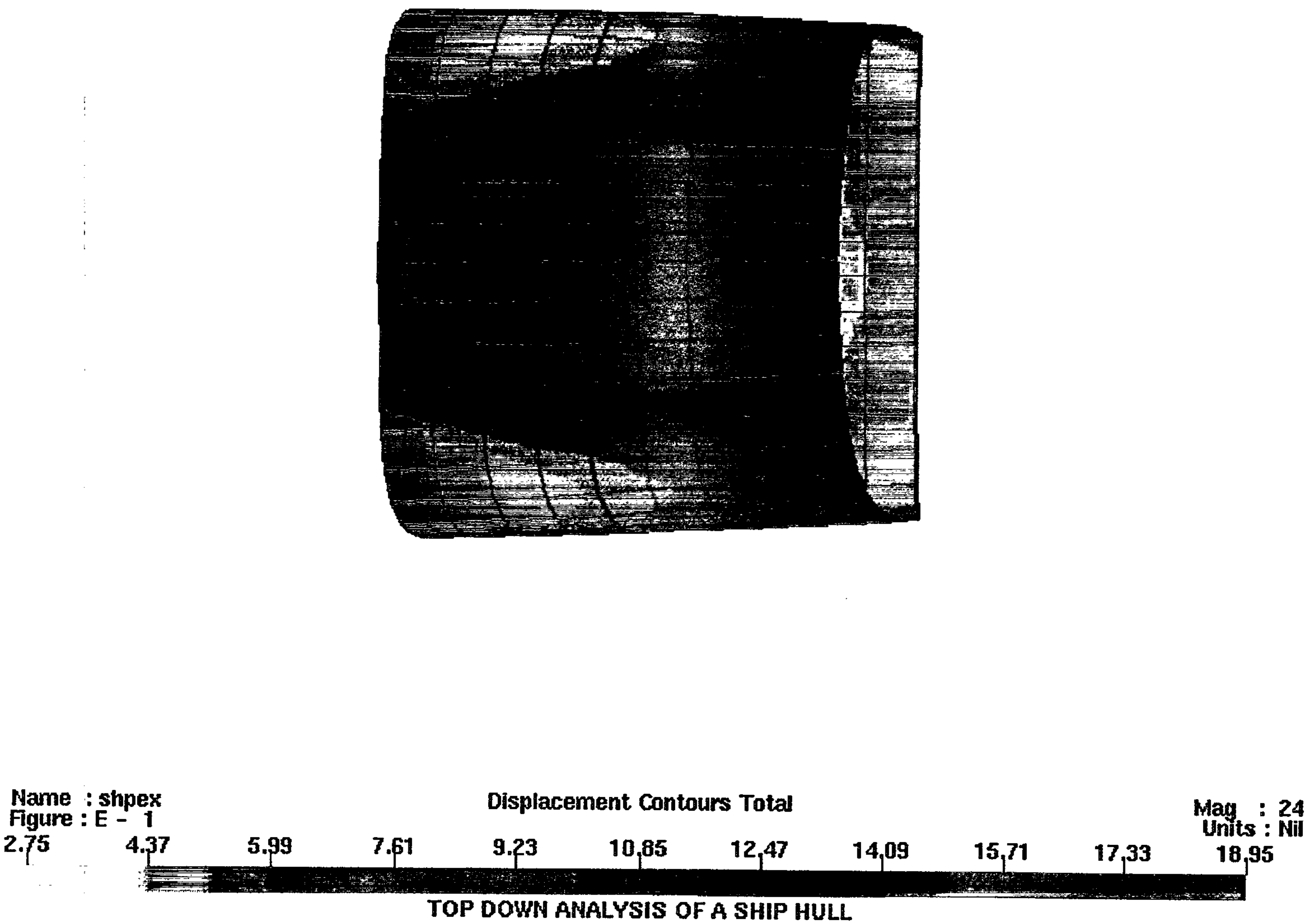

Figure 10: Static Dispacement Fringes in Extracted Model

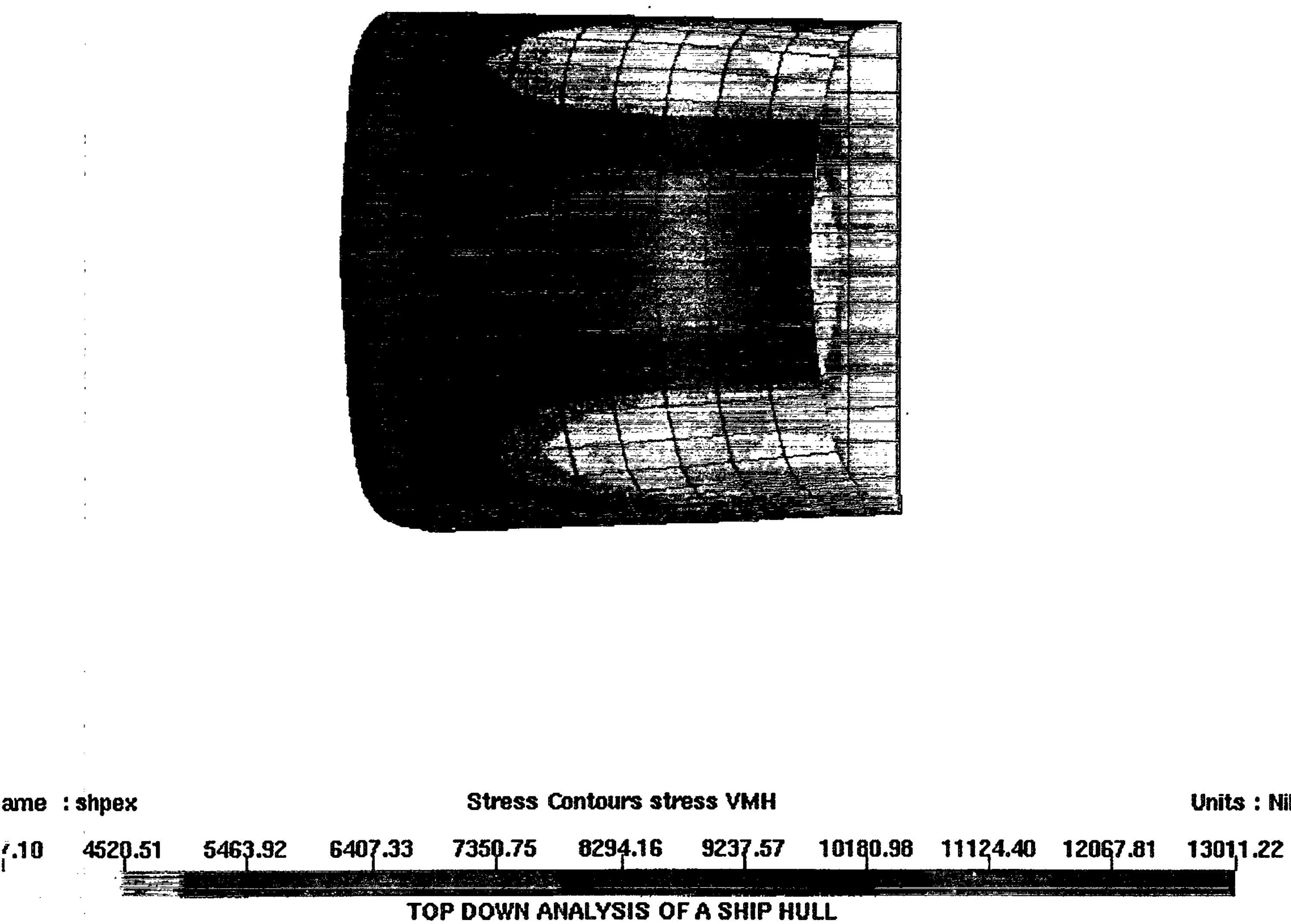

Figure 11: Static Von Mises Stress Fringes in the Extracted Model

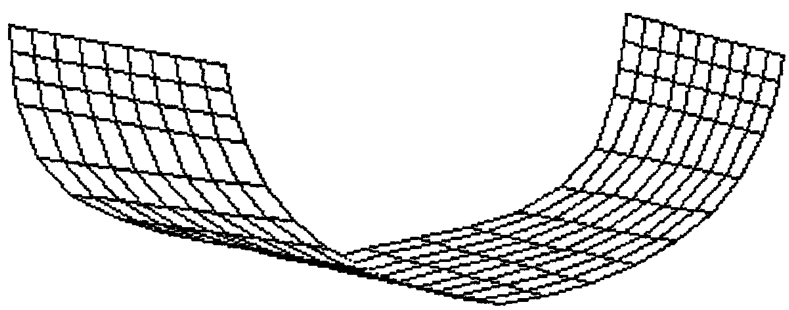

Figure 12: The Geometry of the Reduced Extracted Model

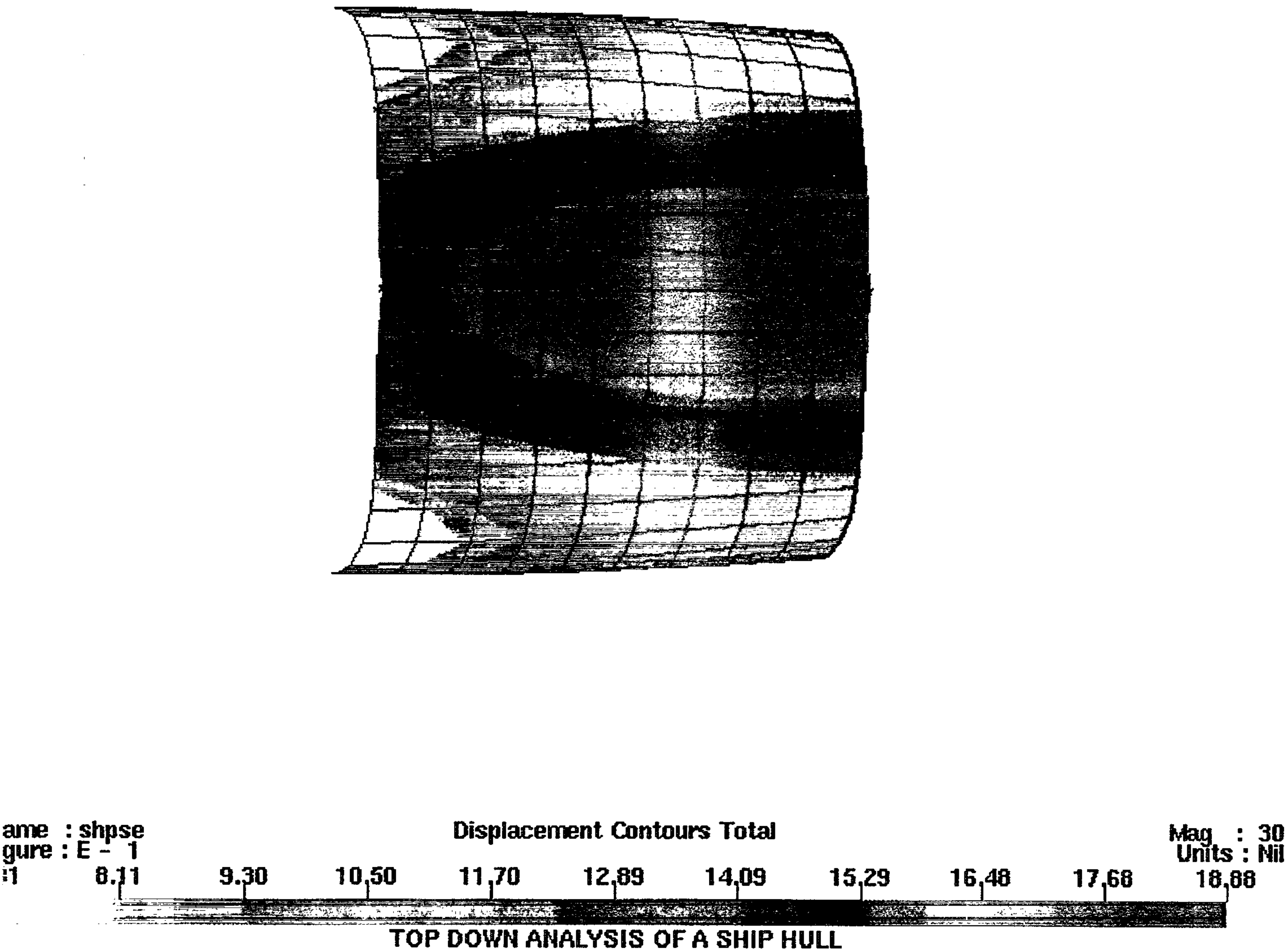

Figure 13: Static Displacement Fringes in the Reduced Extracted Model

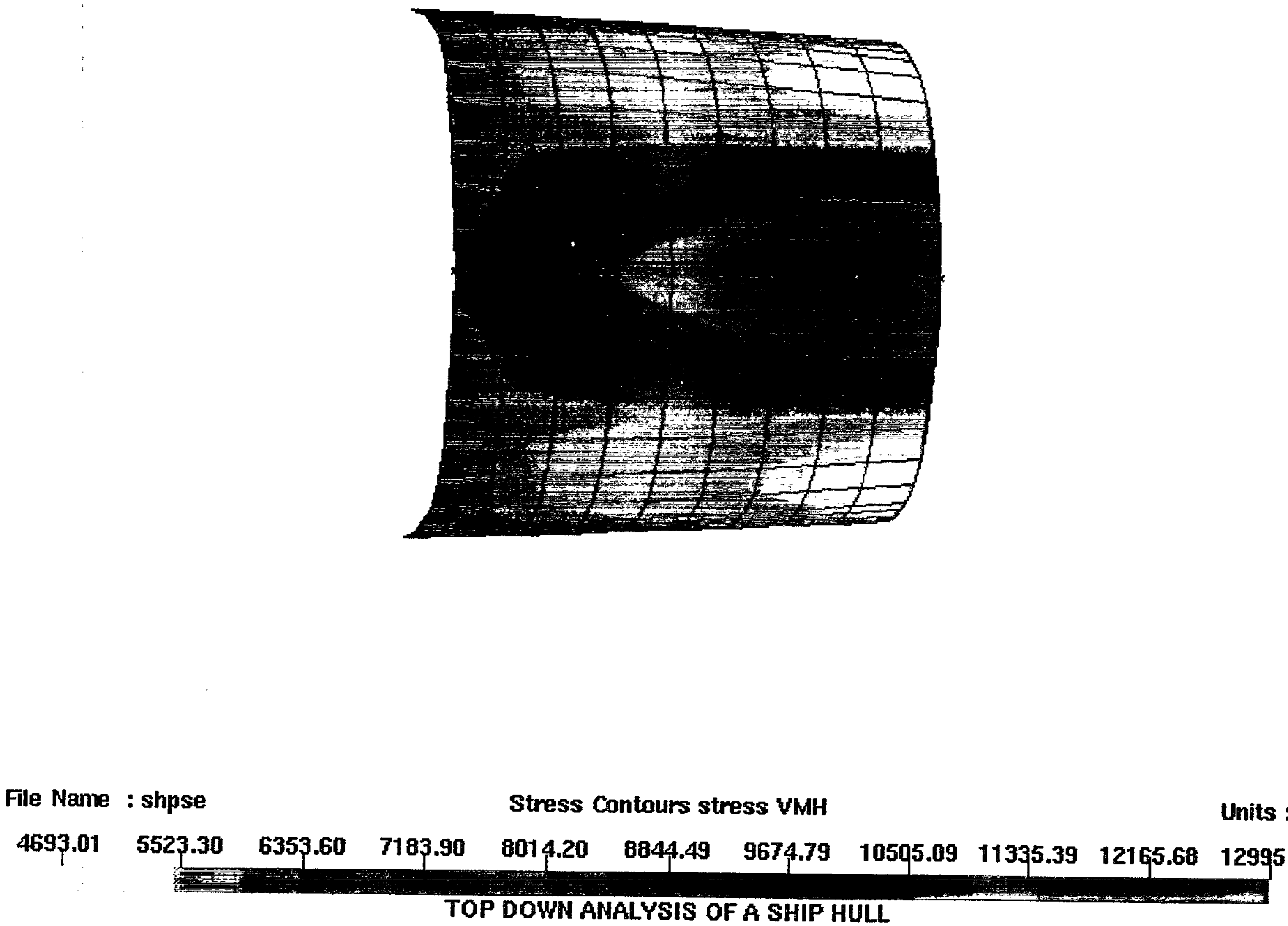

Figure 14: Static Von Mises Stress Fringes in the Reduced Extracted Model

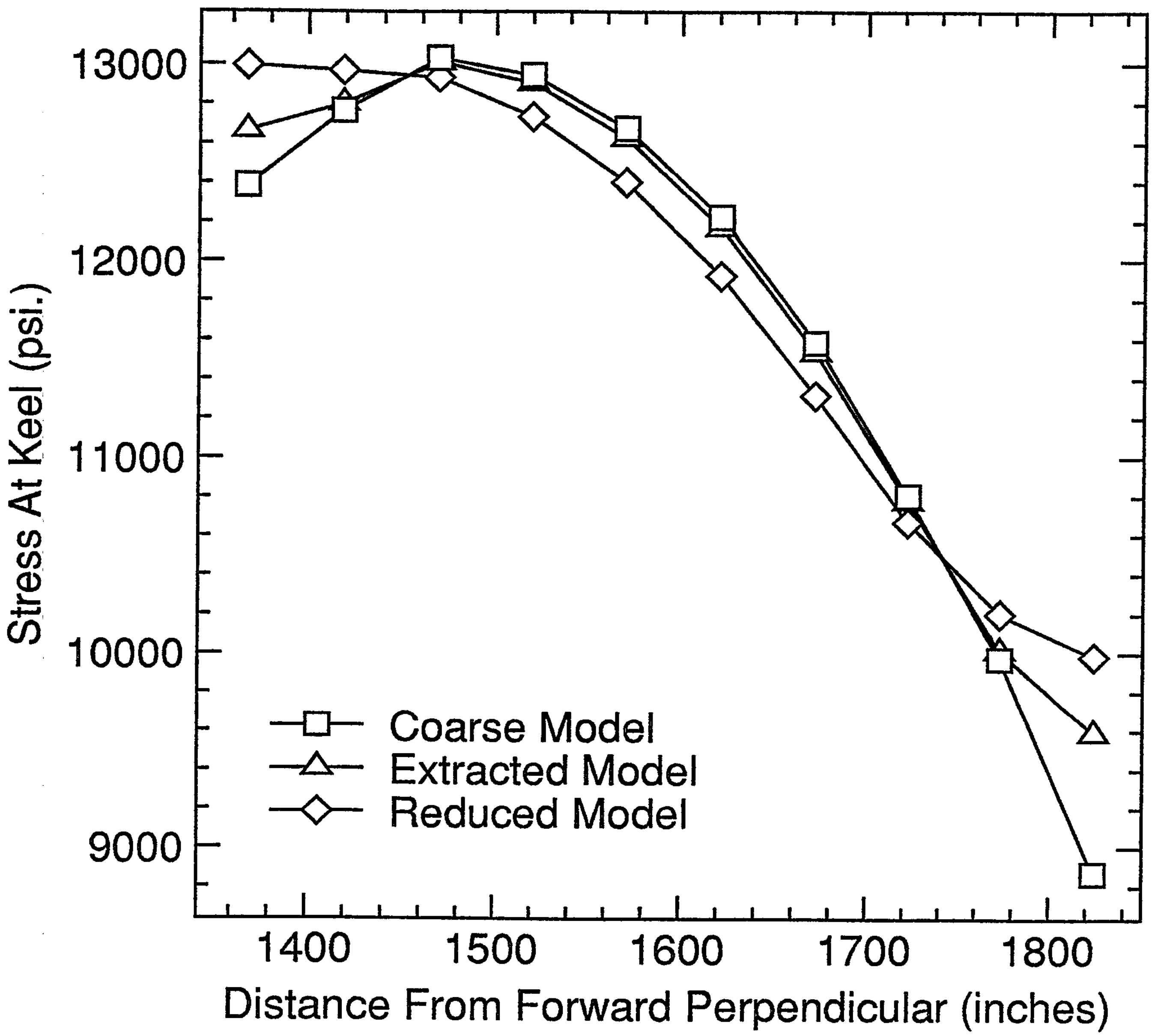

Figure 15: Von Mises Stresses in the Three Models along the Keel

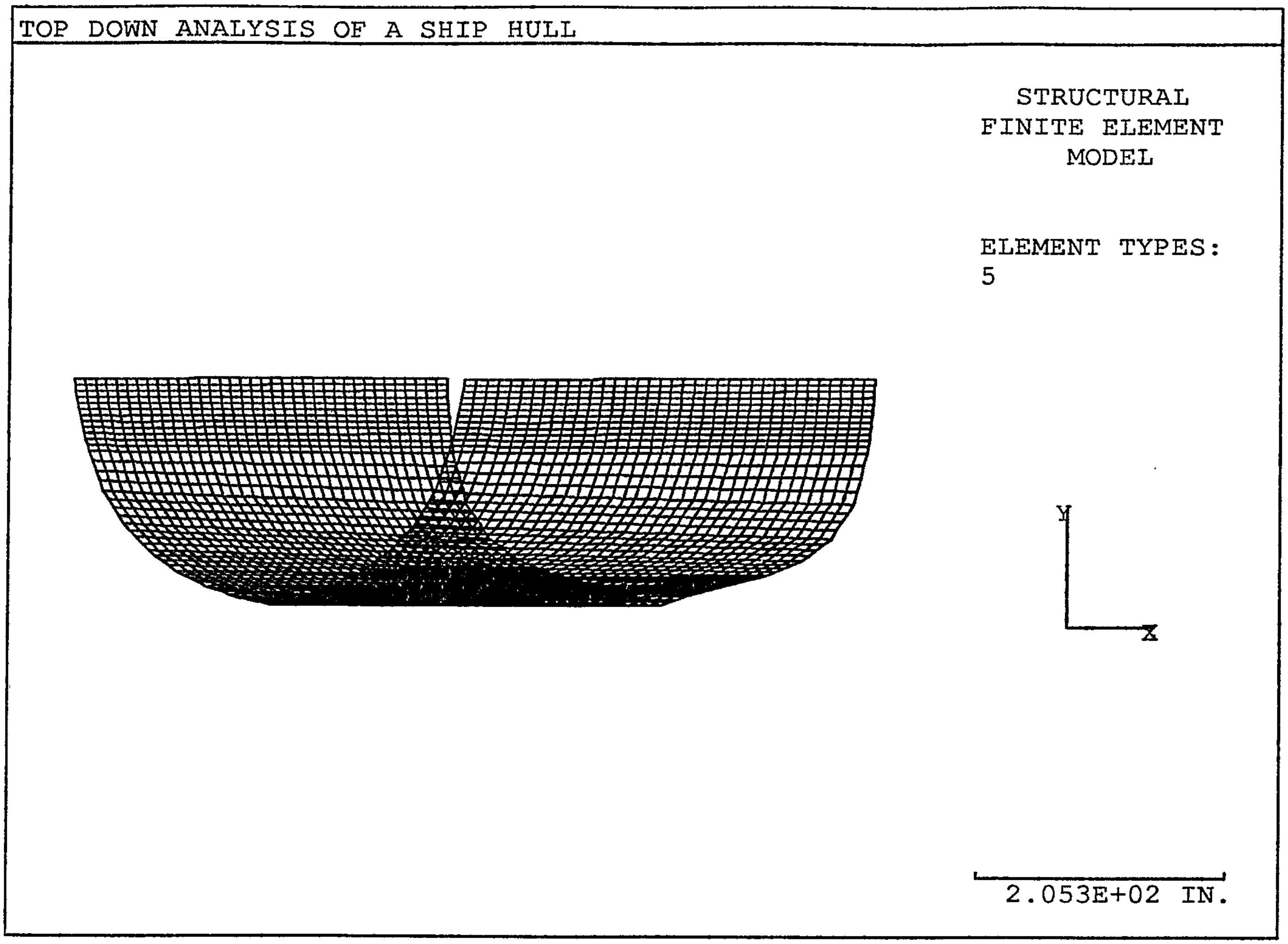

Figure 16: The Refined Reduced Model

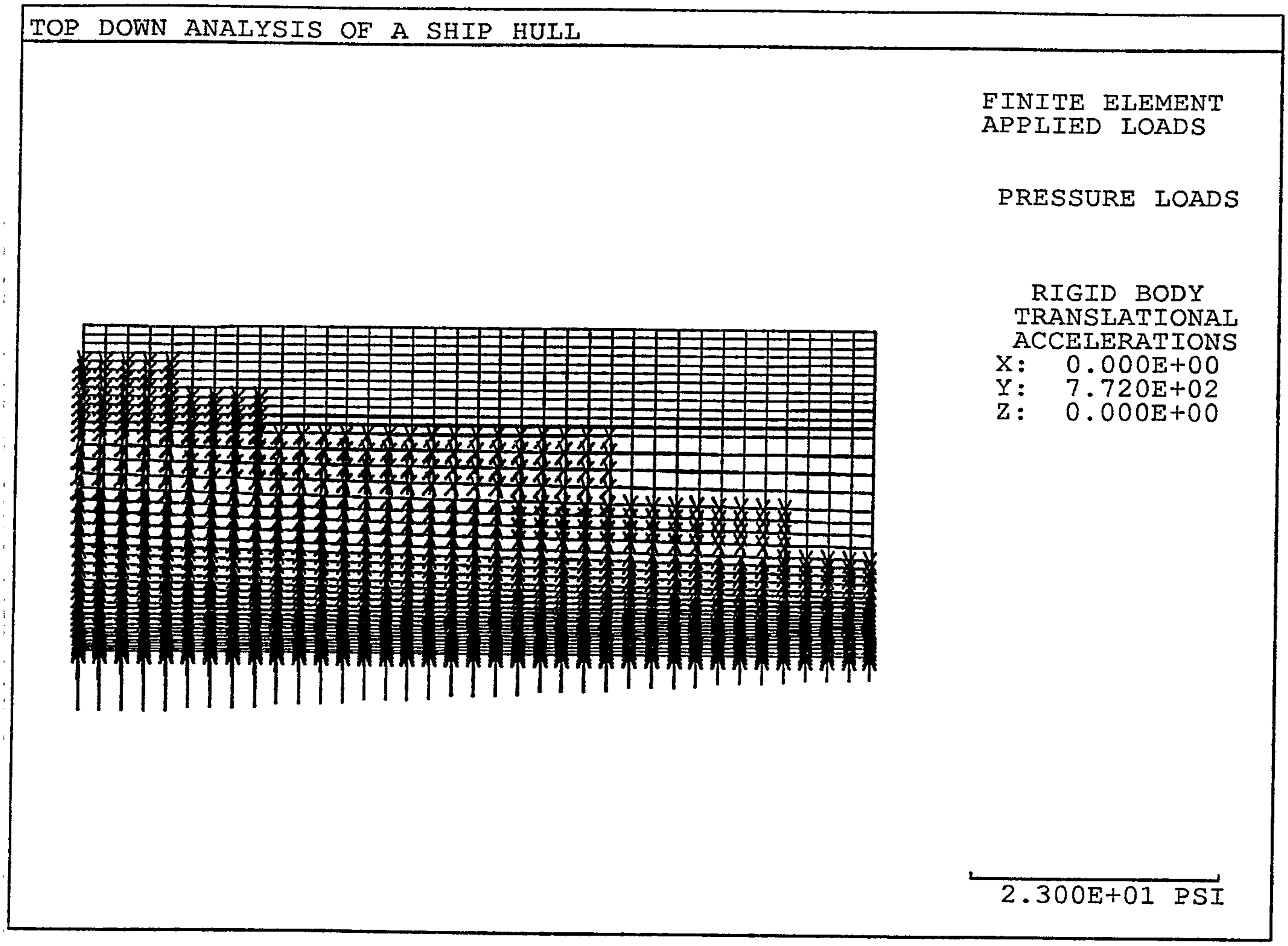

Figure 17: The Pressure Load on the Refined Model Produced by VASFEM

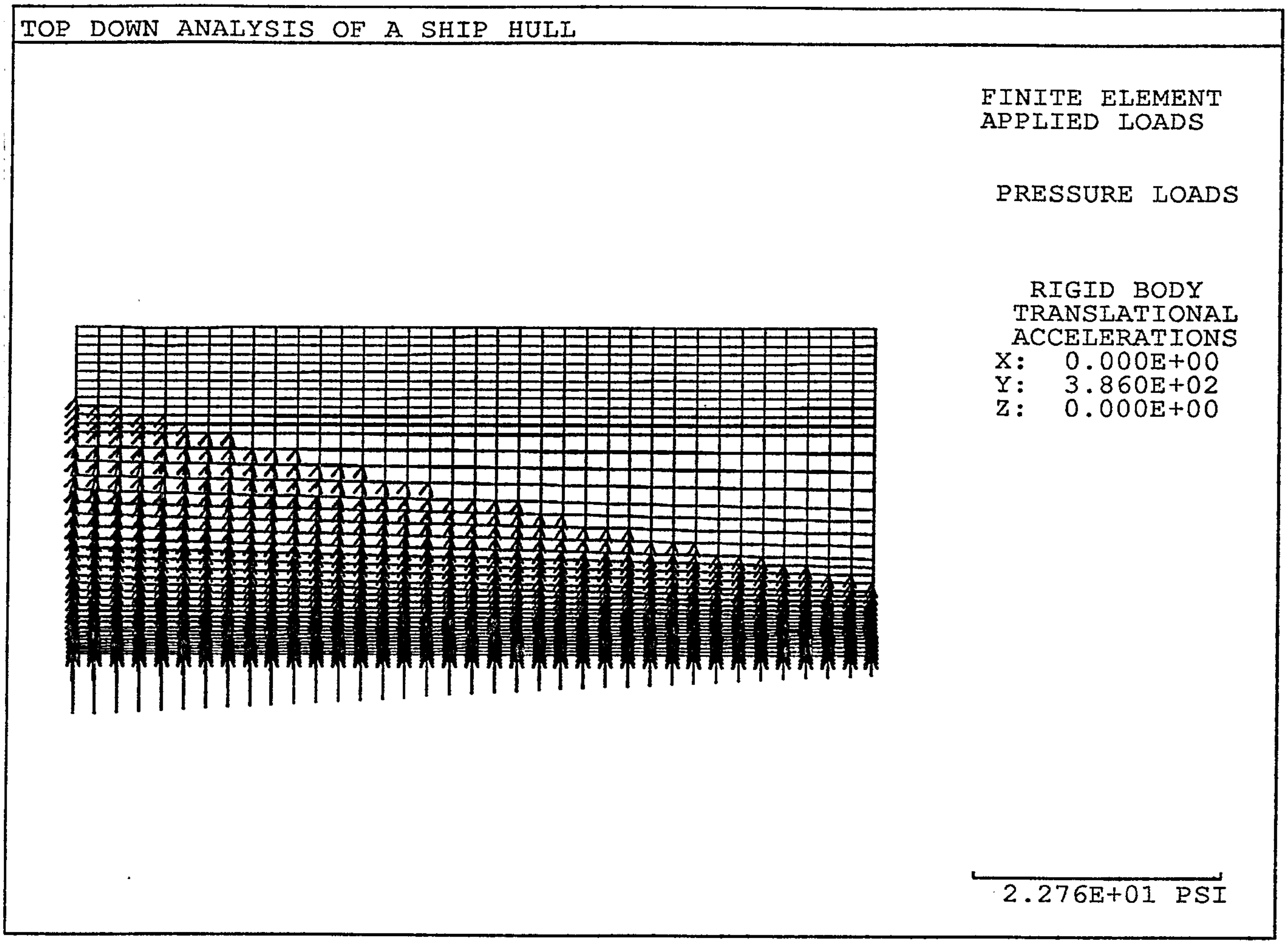

Figure 18: Pressure Load on the Refined Model Produced by EXTRACT

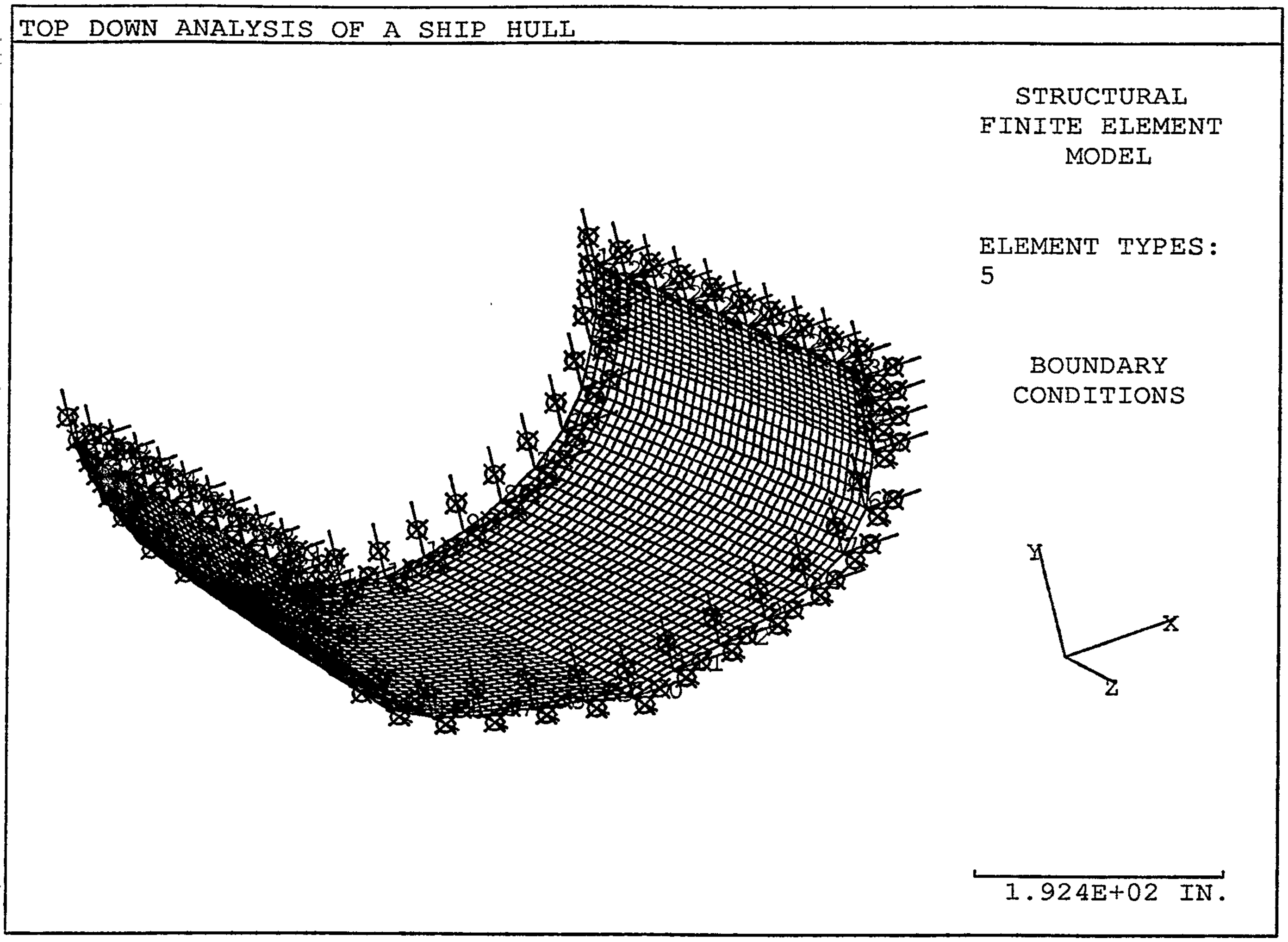

Figure 19: Boundary Conditions Applied to the Refined Model

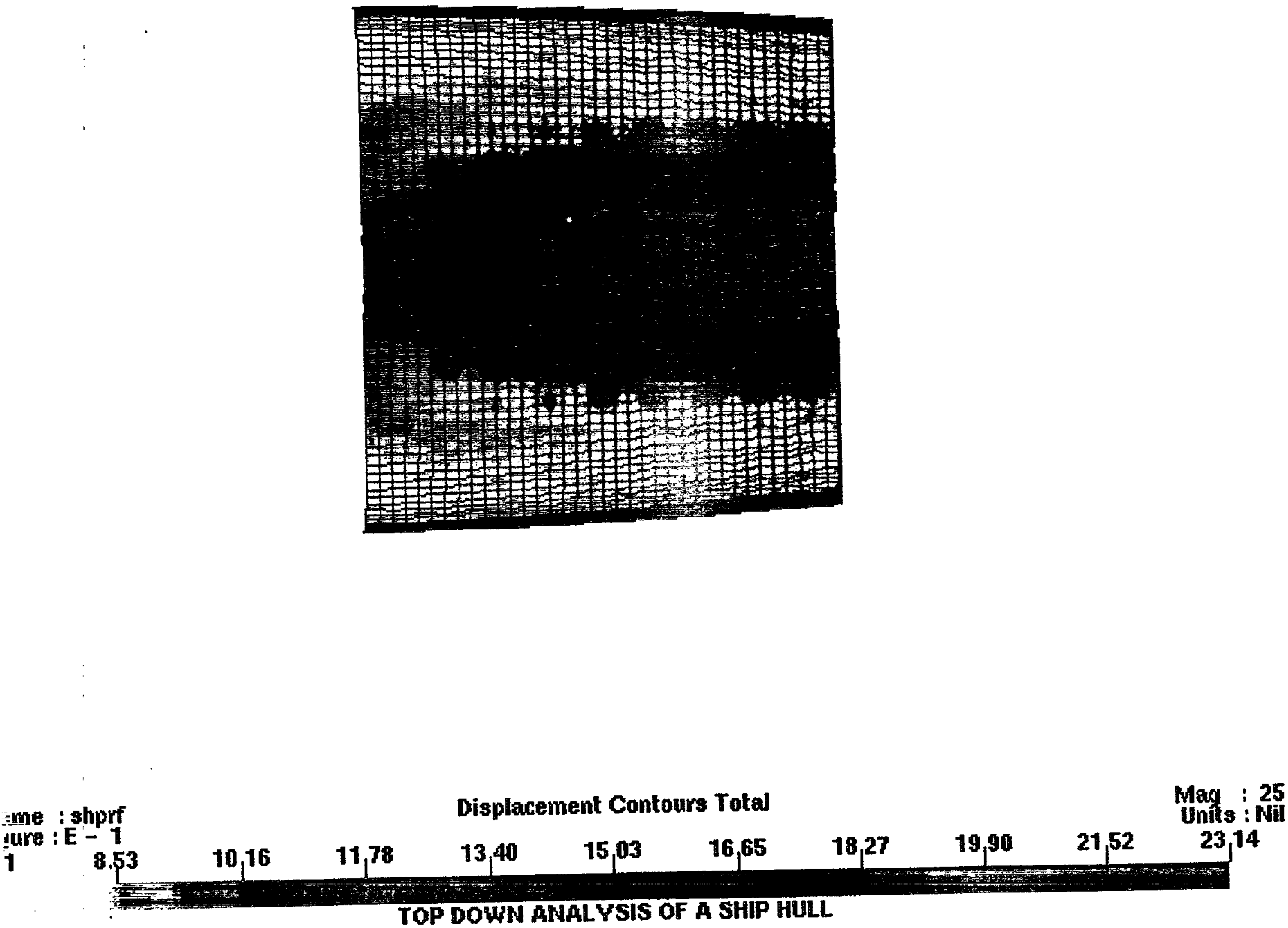

Figure 20: Displacement Fringes for the Refined Model

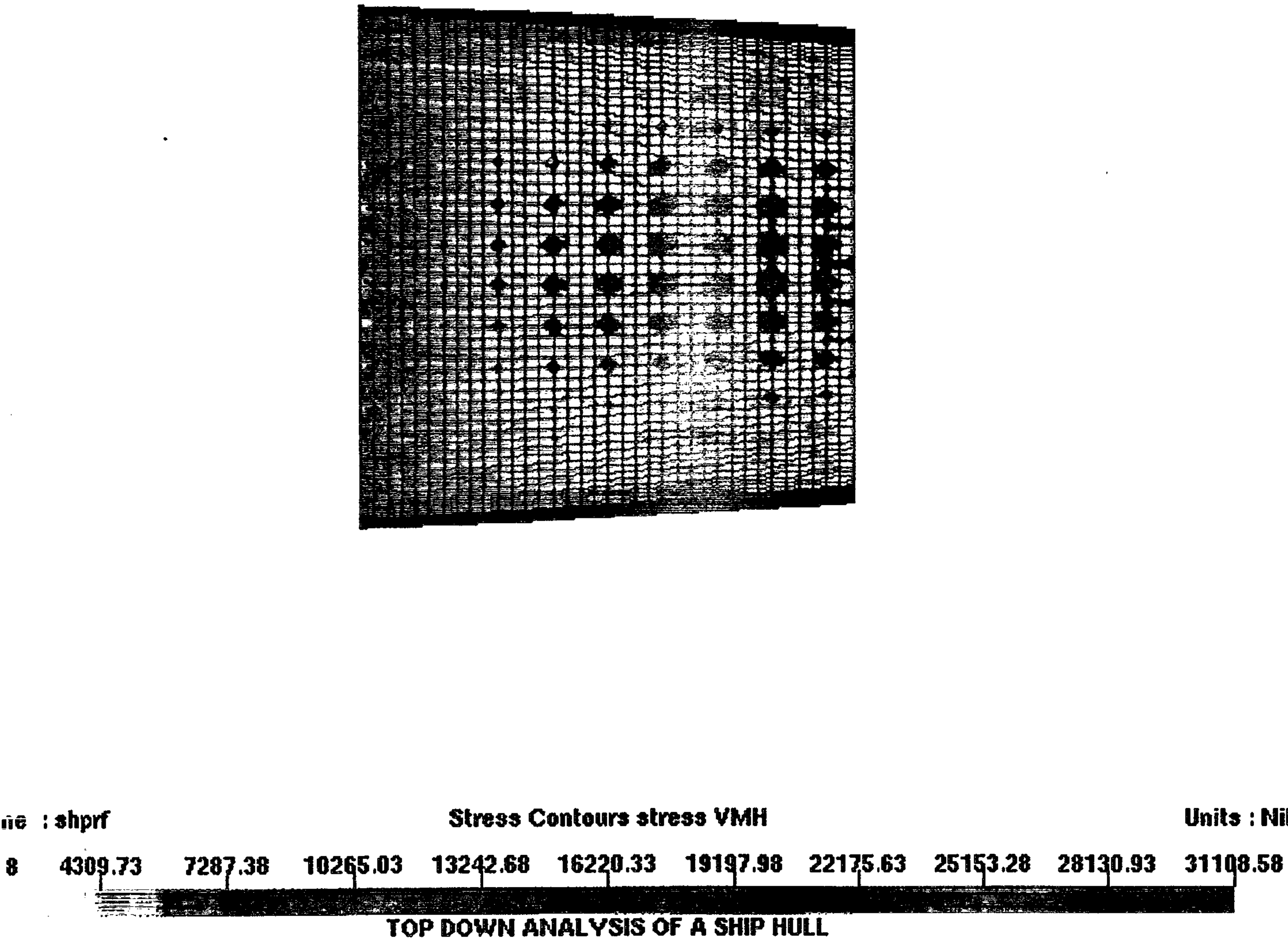

Figure 21: Von Mises Stress Fringes for the Refined Model

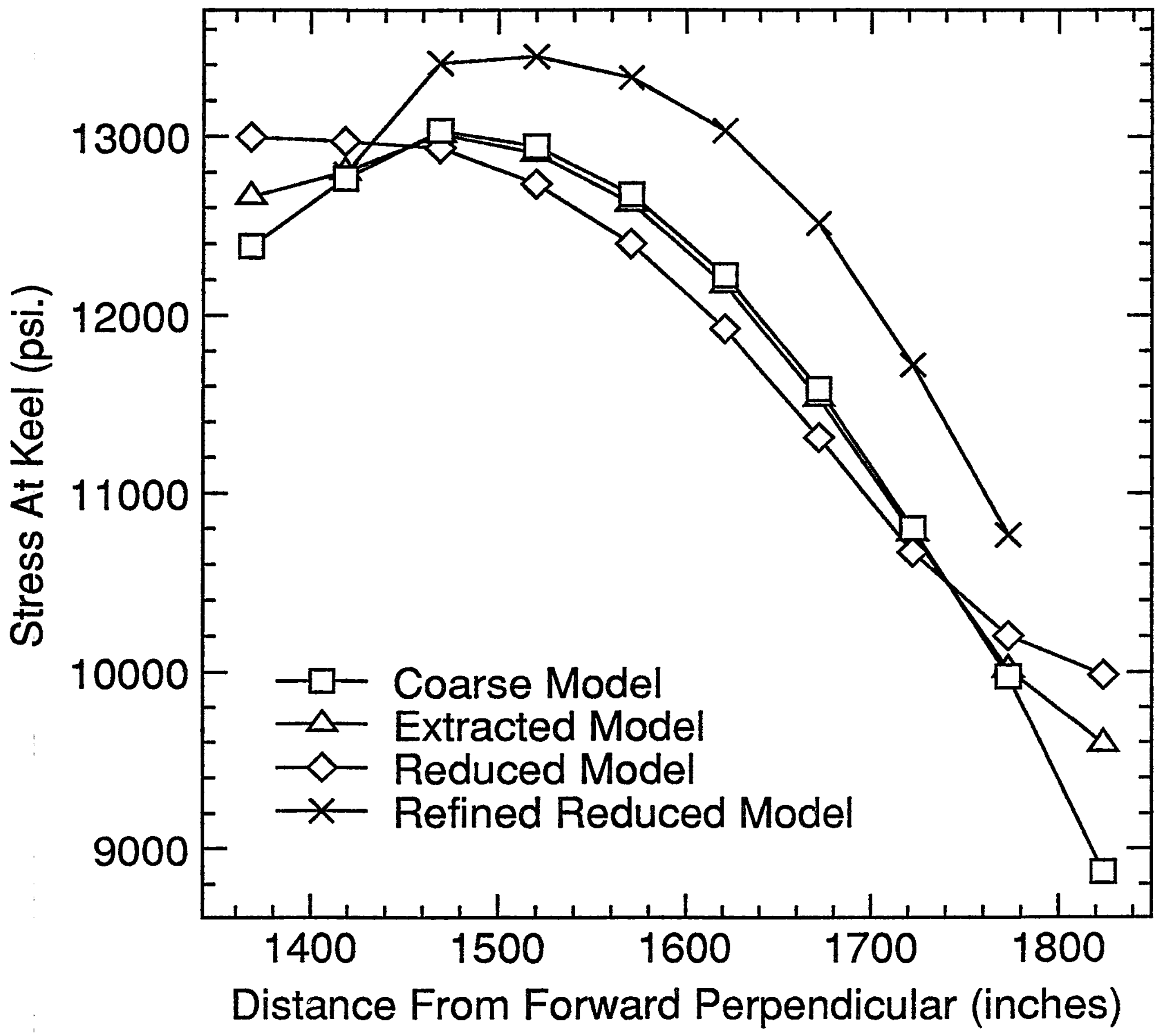

Figure 22: Von Mises Stresses Along the Keel of the Four Models

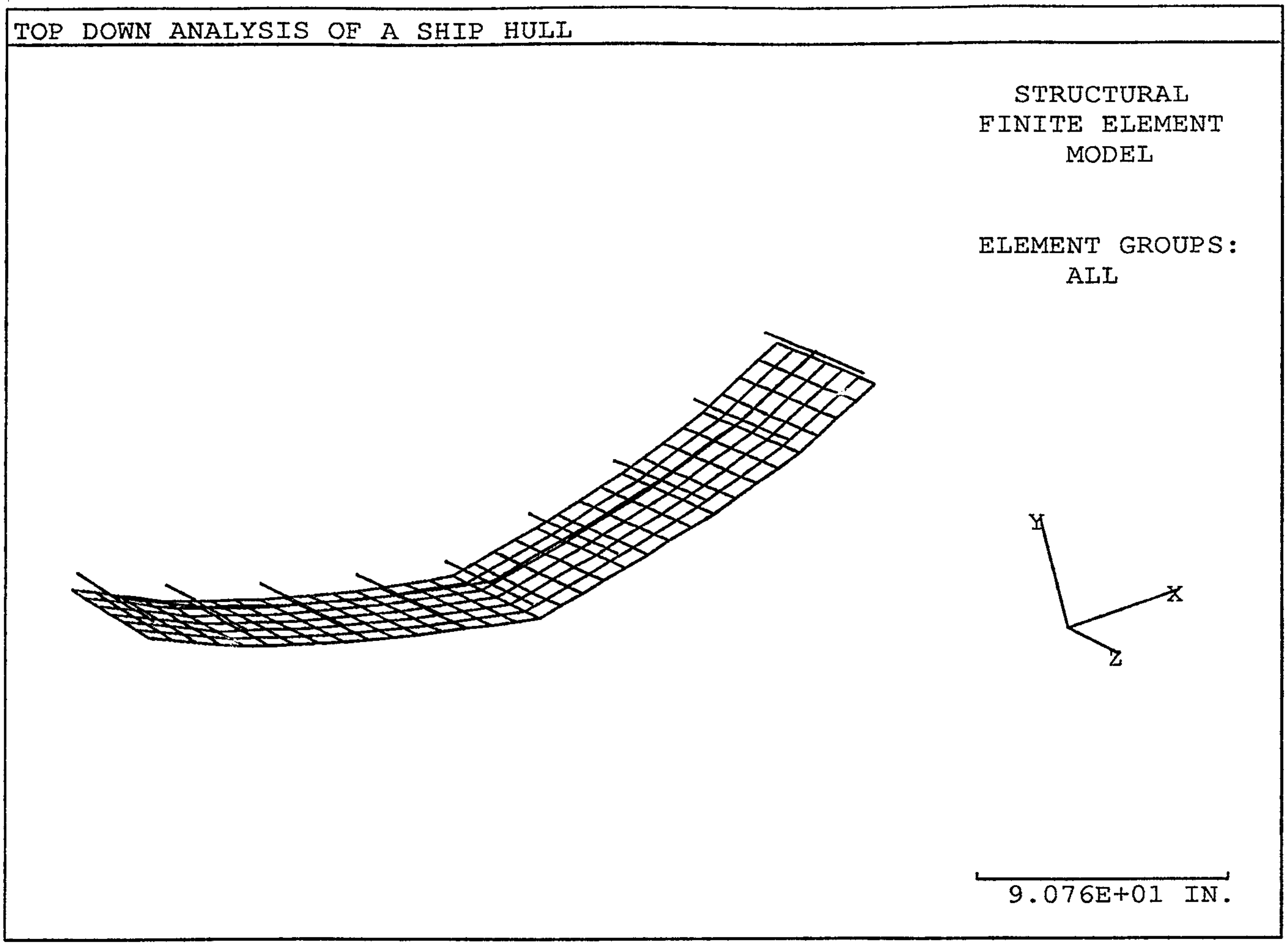

Figure 23: The Single Frame Model

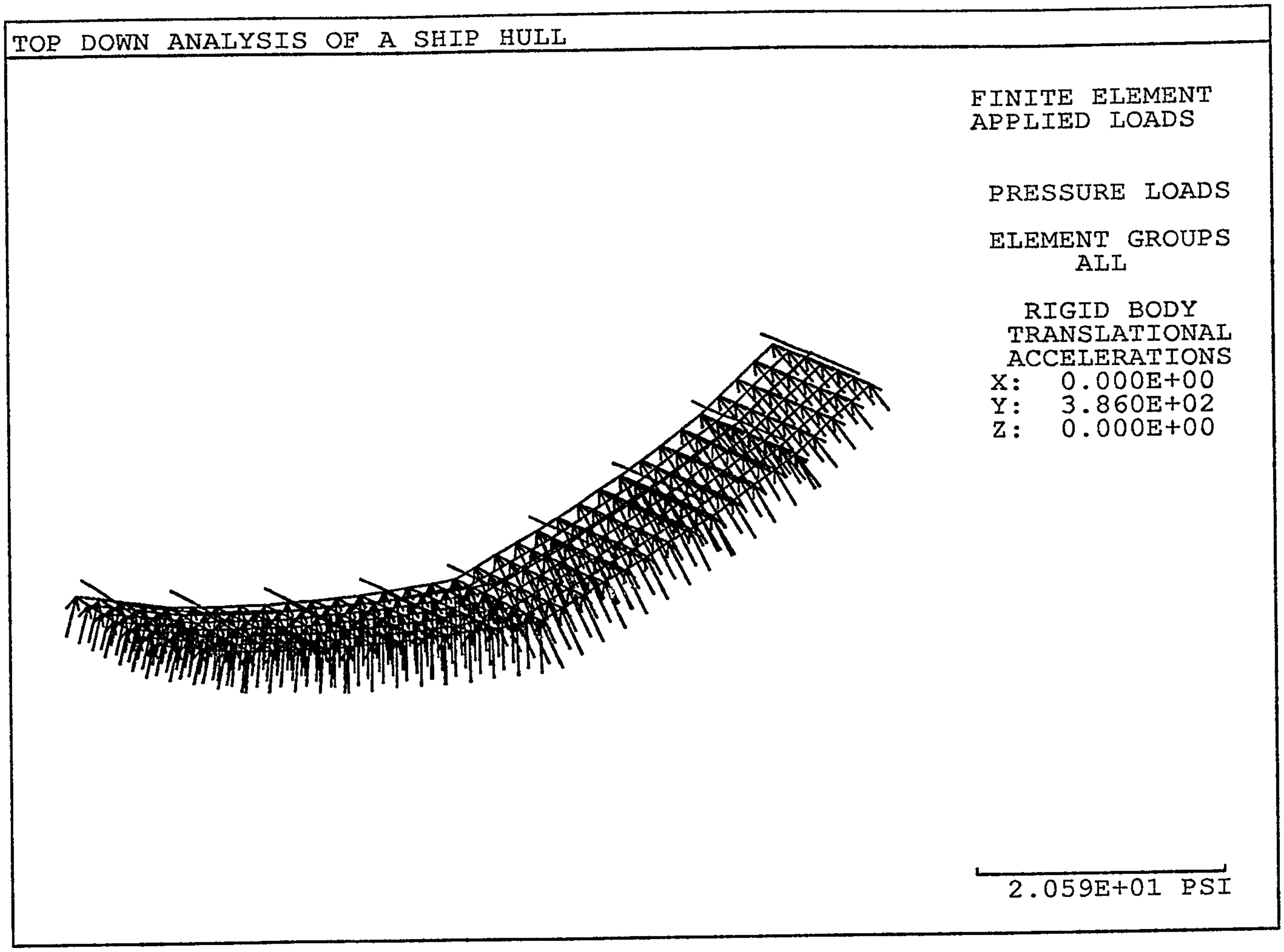

Figure 24: Loading of the Single Frame Model

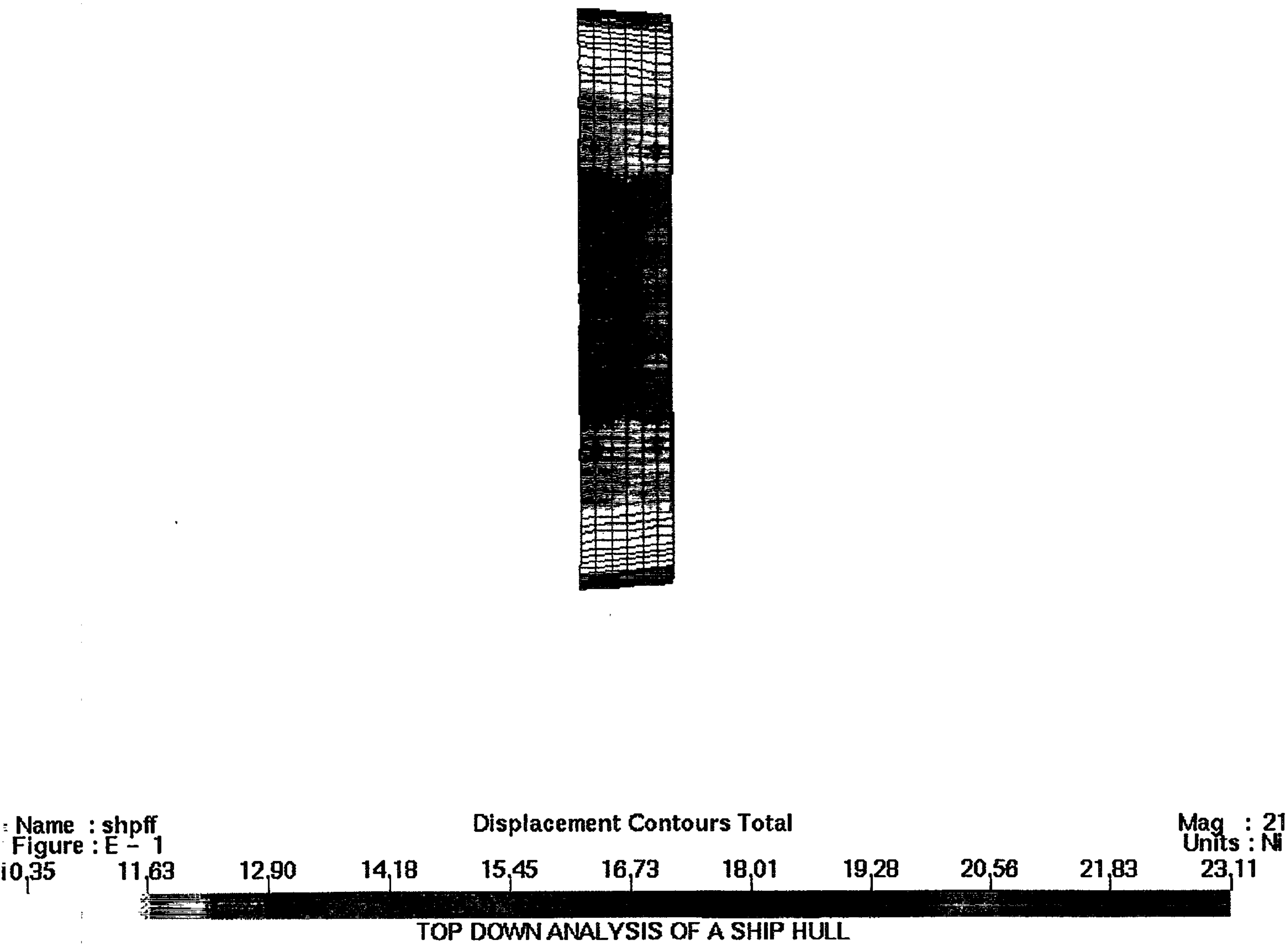

Figure 25: Displacement Fringes for the Single Frame Model

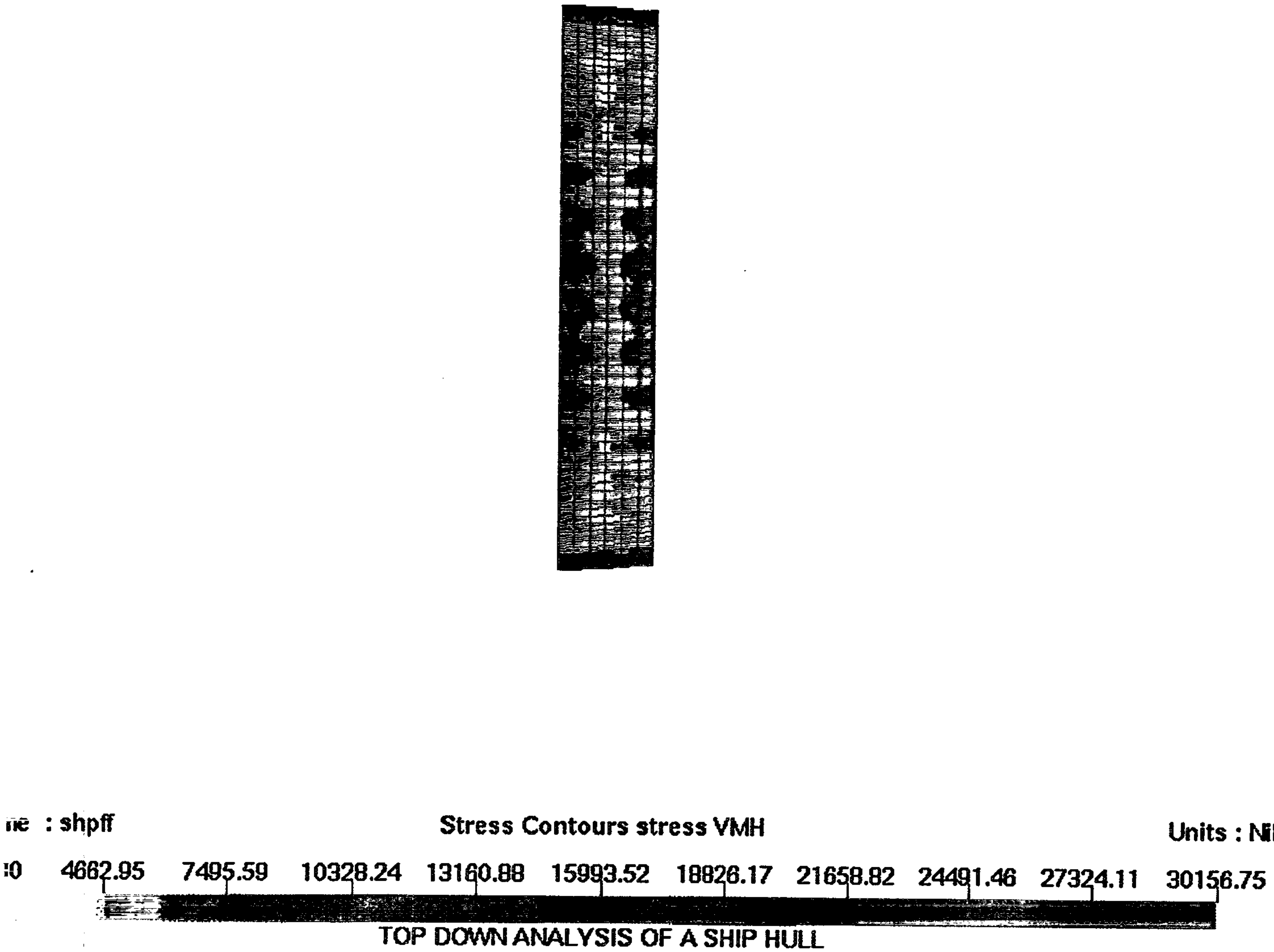

Figure 26: Von Mises Stress Fringes for the Single Frame Model

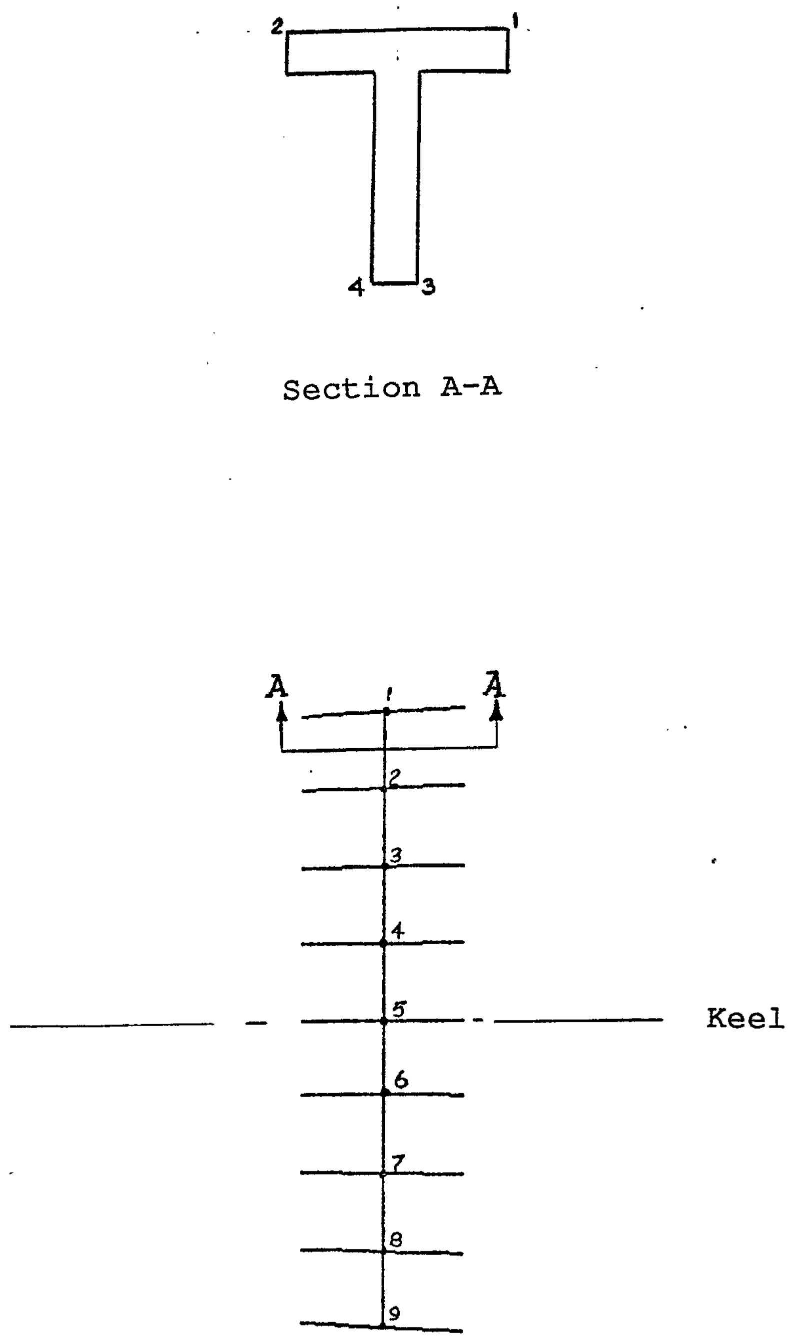

Figure 27: The Beam Grid and Frame Crossection Stress Locations

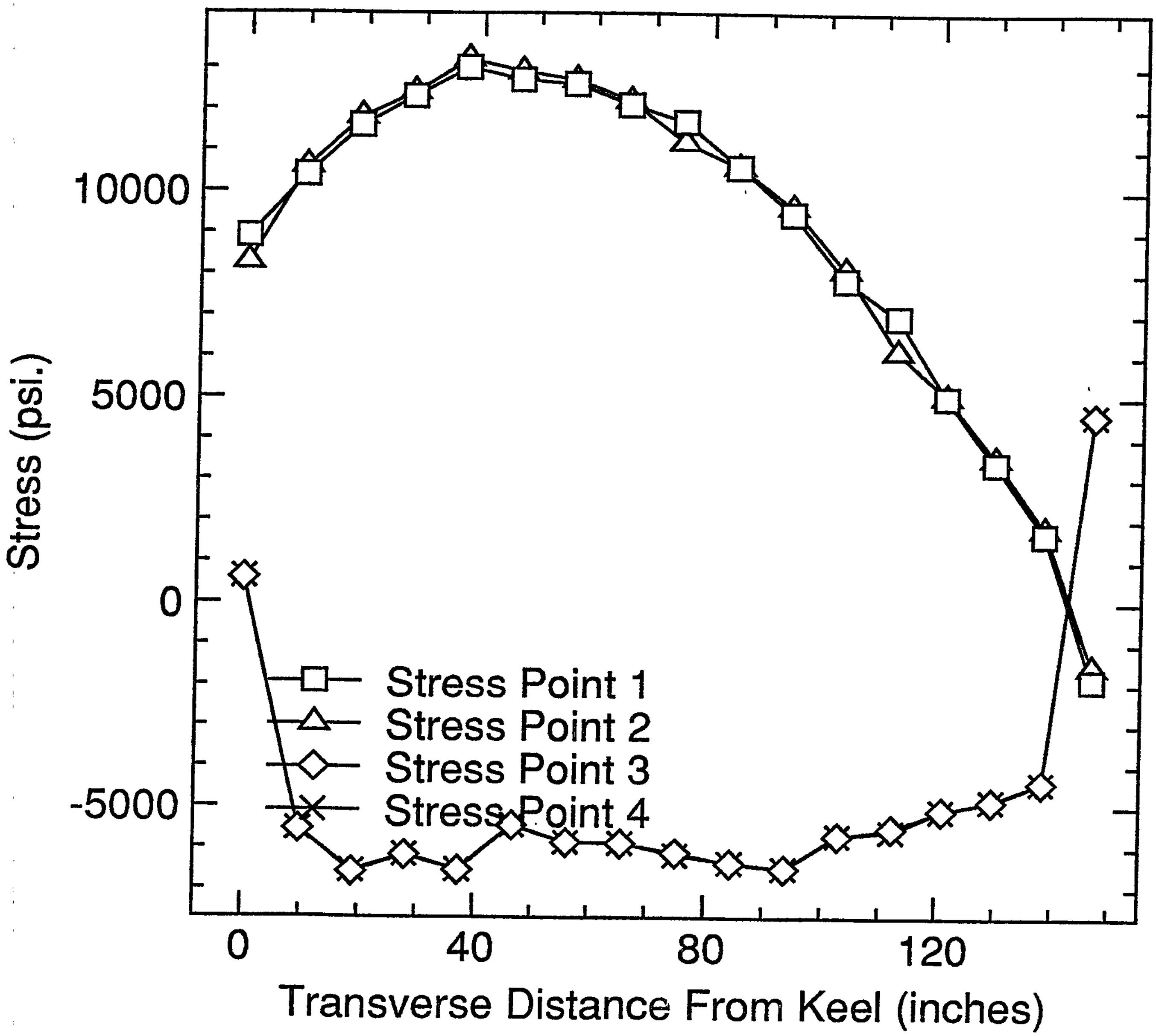

Figure 28: Beam Stresses in the Frame Crossection

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The structural analysis of a ship hull by top-down modelling is described. A finite element analysis of a loaded large coarse model of a ship hull was carried out. After the analysis a section of the model was extracted and displacements from the large model were applied to its boundary nodes as prescribed displacements. The extracted model was loaded with its portion of the load. The displacements and stresses obtained from a finite element analysis of the extracted model were compared with those at corresponding nodes of the coarse model. A reduced size portion of the hull was extracted from the same region and the displacements and stresses compared with those of the coarse and extracted model. The reduced extracted model grid and loading were then refined and displacements and stresses obtained and compared with those of the unrefined model. Then a portion of the refined model was extracted which contained a single frame and portions of the surrounding beams and plates. The displacements and stresses of this model again were compared with those of the model from which it was extracted. The stresses in the frame cross section along its length are shown graphically.

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